

VIIRS Atmosphere - Clouds

H-L Allen Huang

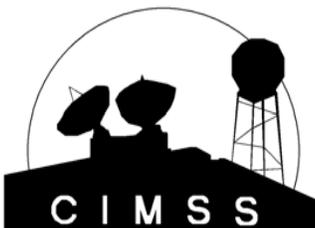
CIMSS - Cooperative Institute for
Meteorological Satellite Studies

University of WI, Madison 

IGARSS NPOESS Workshop

Toronto, Canada

9:30 pm Sunday, June 23, 2002



NPOESS Cloud EDR

Microwaves
6 - 183 GHz

IR
.7 - 13 μm

Visible
.4 - .7 μm

**NPOESS Sensors
to provide cloud
EDR**

VIIRS **CMIS** **CrIS/ATMS**

• Atmospheric Vertical Moisture Profile	
• Atmospheric Vertical Temp Profile	
• Imagery	
• Sea Surface Temperature	
• Sea Surface Winds	
• Soil Moisture	
Aerosol Optical Thickness	
Aerosol Particle Size	
Albedo (Surface)	
Auroral Boundary	
Auroral Imagery	
Cloud Base Height	
Cloud Cover/Layers	
Cloud Effective Particle Size	
Cloud Ice Water Path	
Cloud Liquid Water	
Cloud Optical Depth/Transmittance	
Cloud Top Height	
Cloud Top Pressure	
Cloud Top Temperature	
Currents (Ocean)	

VIIRS:

- Cloud Cover/Layers
- Cloud Effective Particle Size
- Cloud Optical Depth
- Cloud Top Height
- Cloud Top Pressure
- Cloud Top Temperature

CMIS:

- Cloud Base Height
- Cloud Ice Water Path
- Cloud Liquid Water



NPOESS Cloud EDR - Algorithm Documentation

VIIRS: http://npoesslib.ipo.noaa.gov/atbd_viirs.htm

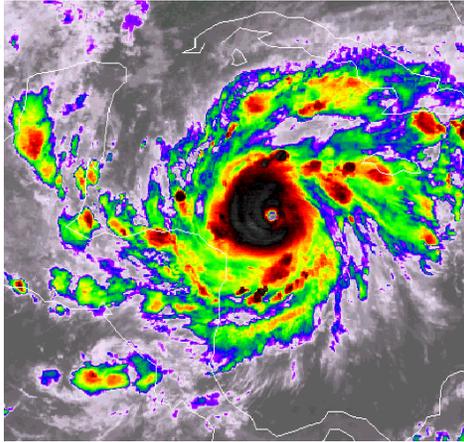
- Cloud Cover/Layers
- Cloud Effective Particle Size
- Cloud Optical Depth
- Cloud Top Height
- Cloud Top Pressure
- Cloud Top Temperature
- Cloud Base Height

CMIS*:

- Cloud Ice Water Path
 - Cloud Liquid Water
- *Not available yet



NPOESS VIS/IR Cloud Signature



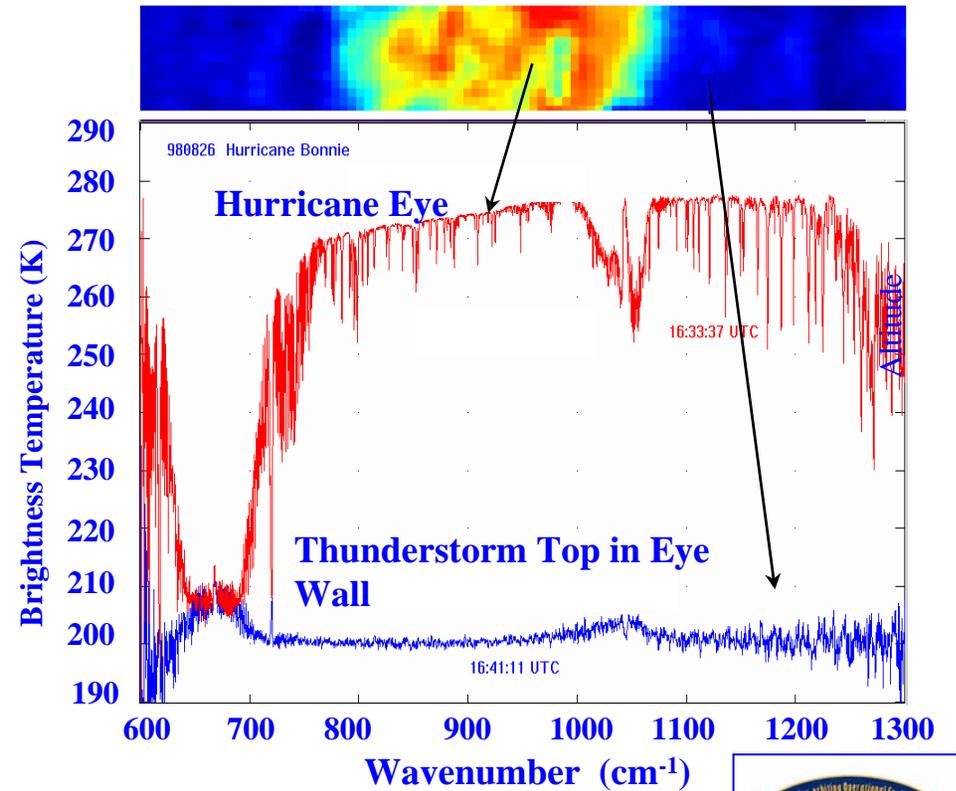
Infrared image

VIIRS



Visible Imagery

CrIS
NAST-I 10 km Cross
Track Image



VIIRS Imaging (I) and Radiometric (M) Spectral Bands

VIS/NIR

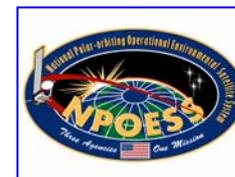
	Band No.	Wave-length (μm)	Horiz Sample Interval (km Downtrack x Crosstrack)		DRIVING EDR(s)	Radiance Range	Ltyp or Ttyp	Signal to Noise Ratio (dimensionless) or NEΔT (Kelvins)			
			Nadir	End of Scan				Nadir	E.O.S.	Required	Margin
VIS/NIR FPA Silicon PIN Diodes	M 1	0.412	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	44.9 200	753 1758	435 1016	352 841	23.5% 20.7%
	M 2	0.445	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	40 230	975 2451	563 1415	380.1 886	48.1% 59.7%
	M 3	0.488	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	32 270	1065 3045	615 1758	415.6 963	48.0% 82.6%
	M 4	0.555	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	21 285	931 3272	538 1889	361.8 1018	48.6% 85.6%
	I 1	0.645	0.371 x 0.387	0.80 x 0.789	Imagery EDR	Single	22	326	188	130.7	43.9%
	M 5	0.672	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	10 233	637 3319	368 1916	242.1 1379	52.0% 38.9%
	M 6	0.752	0.742 x 0.776	1.60 x 1.58	Atmospheric Corr'n	Single	9.6	550	318	199.1	59.5%
	I 2	0.865	0.371 x 0.387	0.80 x 0.789	NDVI	Single	25	435	251	151.2	66.2%
	M 7	0.865	0.742 x 0.259	1.60 x 1.58	Ocean Color Aerosols	Low High	6.4 139	864 3714	499 2144	215.3 1059	131% 102%
	CCD	DNB	0.7	0.742 x 0.742	0.742 x 0.742	Imagery EDR	Var.	6.70E-05	30.0	6.6	6
S/MWIR PV HgCdTe	M 8	1.24	0.742 x 0.776	1.60 x 1.58	Cloud Particle Size	Single	5.4	222	128	101	27.1%
	M 9	1.378	0.742 x 0.776	1.60 x 1.58	Cirrus/Cloud Cover	Single	6	246	142	82.7	71.9%
	I 3	1.61	0.371 x 0.387	0.80 x 0.789	Binary Snow Map	Single	7.3	133	77	6	1178%
	M 10	1.61	0.742 x 0.776	1.60 x 1.58	Snow Fraction	Single	7.3	857	495	342.2	44.5%
	M 11	2.25	0.742 x 0.776	1.60 x 1.58	Clouds	Single	0.12	25.8	14.9	10	49.0%
	I 4	3.74	0.371 x 0.387	0.80 x 0.789	Imagery Clouds	Single	270 K	0.446 K	0.773 K	2.500 K	223%
	M 12	3.70	0.742 x 0.776	1.60 x 1.58	SST	Single	270 K	0.129 K	0.223 K	0.396 K	77.8%
	M 13	4.05	0.742 x 0.259	1.60 x 1.58	SST Fires	Low High	300 K 380 K	0.024 K 0.174 K	0.042 K 0.302 K	0.107 K 0.423 K	155% 40.1%
LWIR PV HCT	M 14	8.55	0.742 x 0.776	1.60 x 1.58	Cloud Top Properties	Single	270 K	0.027 K	0.046 K	0.091 K	97.5%
	M 15	10.762	0.742 x 0.776	1.60 x 1.58	SST	Single	300 K	0.020 K	0.034 K	0.070 K	105%
	I 5	11.45	0.371 x 0.387	0.80 x 0.789	Cloud Imagery	Single	210 K	0.383 K	0.663 K	1.500 K	126%
	M 16	12.01	0.742 x 0.776	1.60 x 1.58	SST	Single	300 K	0.030 K	0.052 K	0.072 K	39.6%

SW/MWIR

LWIR

All Bands Have Comfortable Margin Above EDR-Derived SNR Requirements

5 I Bands & 16 M Bands



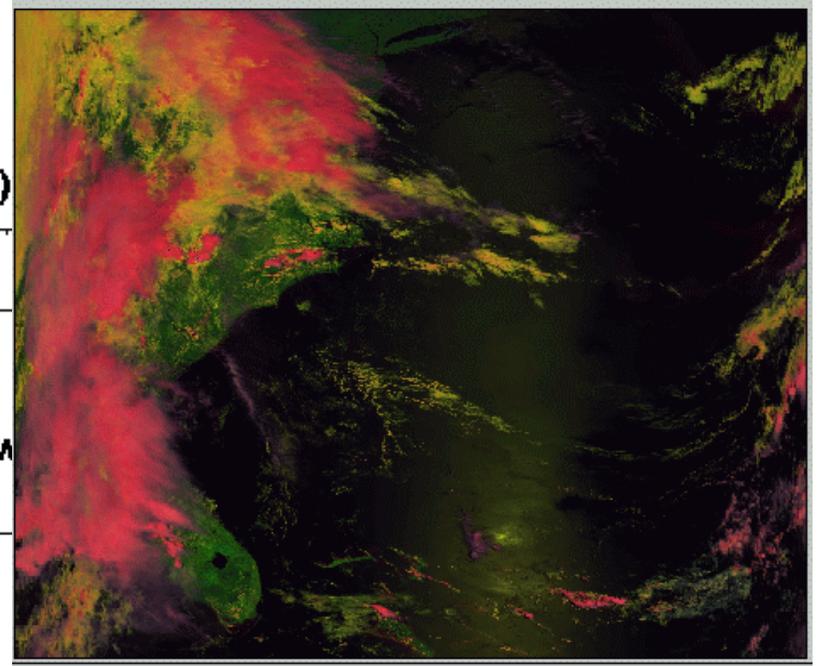
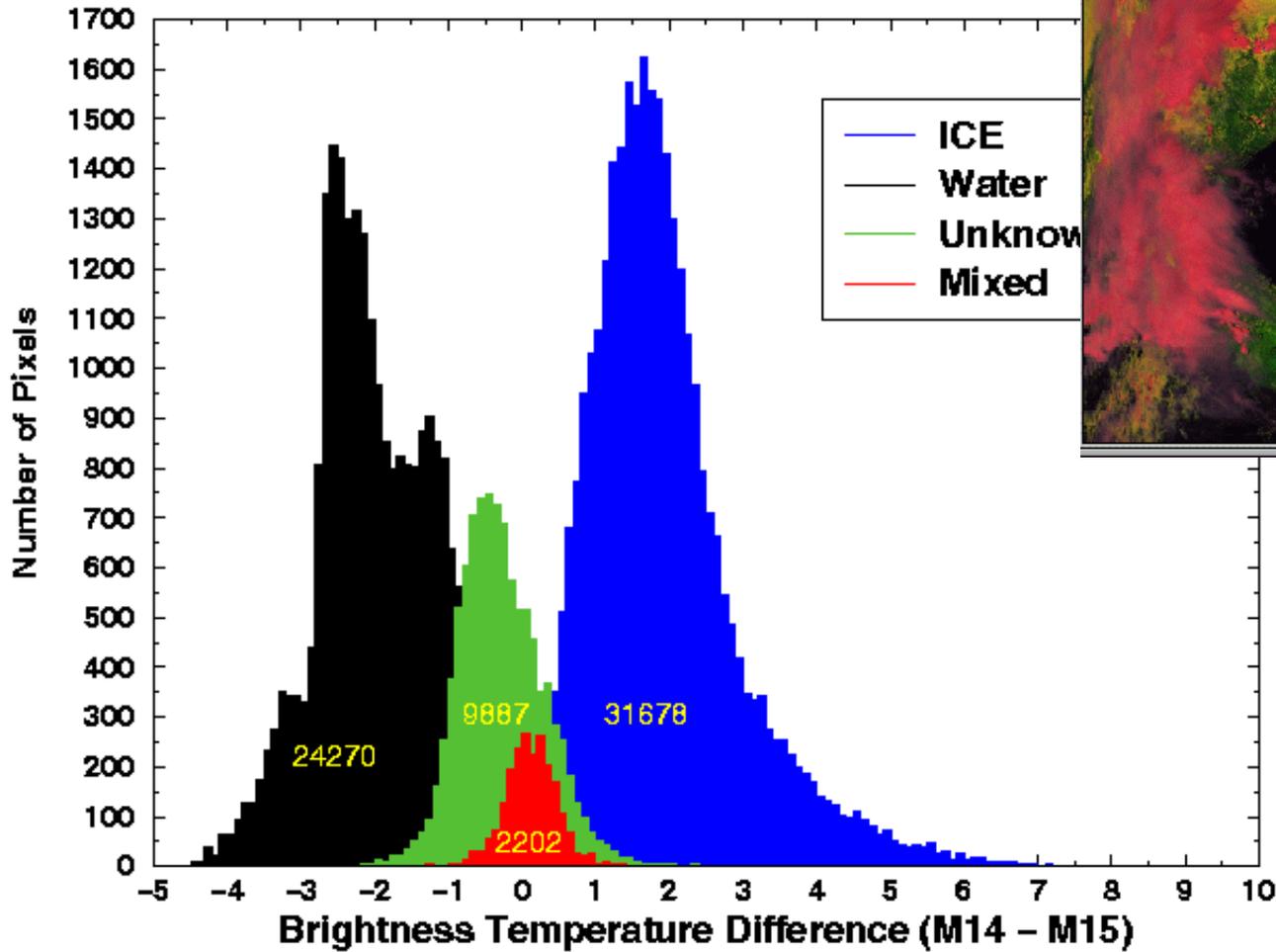
VIIRS Bands used in Cloud Mask

3 I Bands &
11 M Bands

VIIRS Bands	Wavelength (μm)	Note
M4	0.555	VIS/NIR
M5	0.672	VIS/NIR
I2	0.865	VIS/NIR
M7	0.865	VIS/NIR
M9	1.378	SW/MWIR
M10	1.61	SW/MWIR
M11	2.25	SW/MWIR
I4	3.74	SW/MWIR
M12	3.7	SW/MWIR
M13	4.05	SW/MWIR
M14	8.55	LWIR
M15	10.7625	LWIR
I5	11.45	LWIR
M16	12.0125	LWIR



VIIRS Cloud Phase Detection MODIS - Hune 1, 2001 (16:00-16:05 UTC)



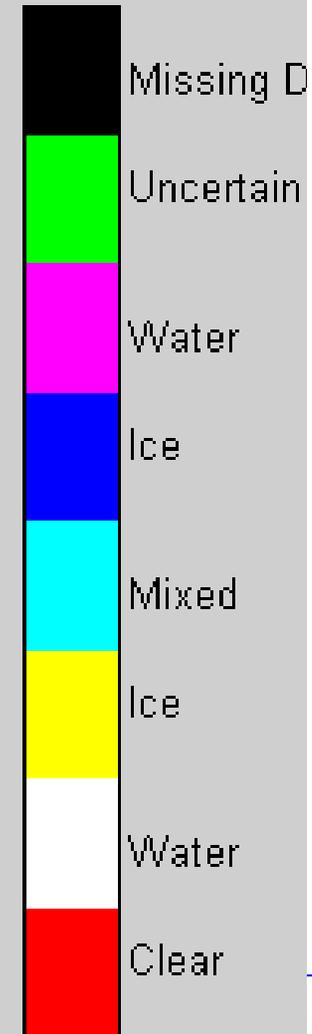
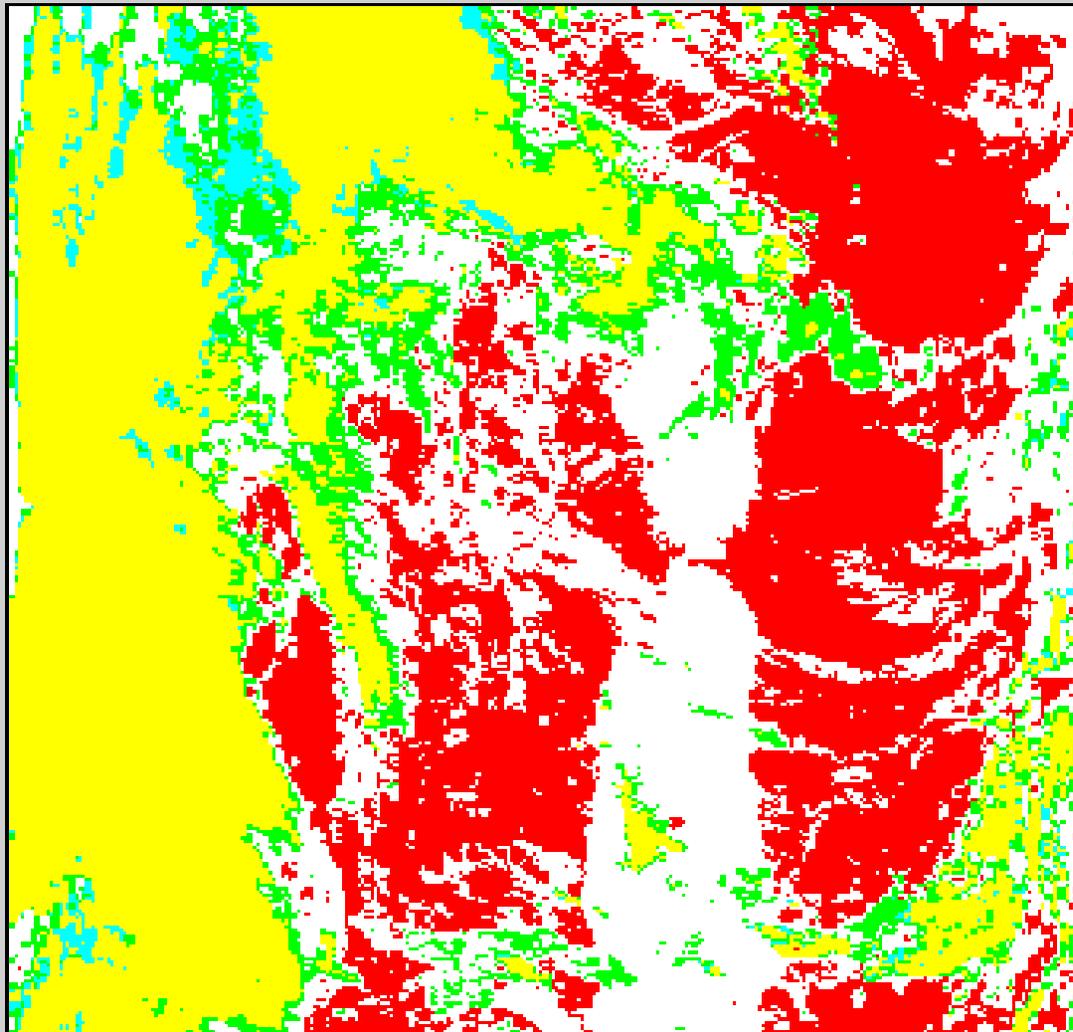
Cloud Mask/Phase

Clear Pixels not shown

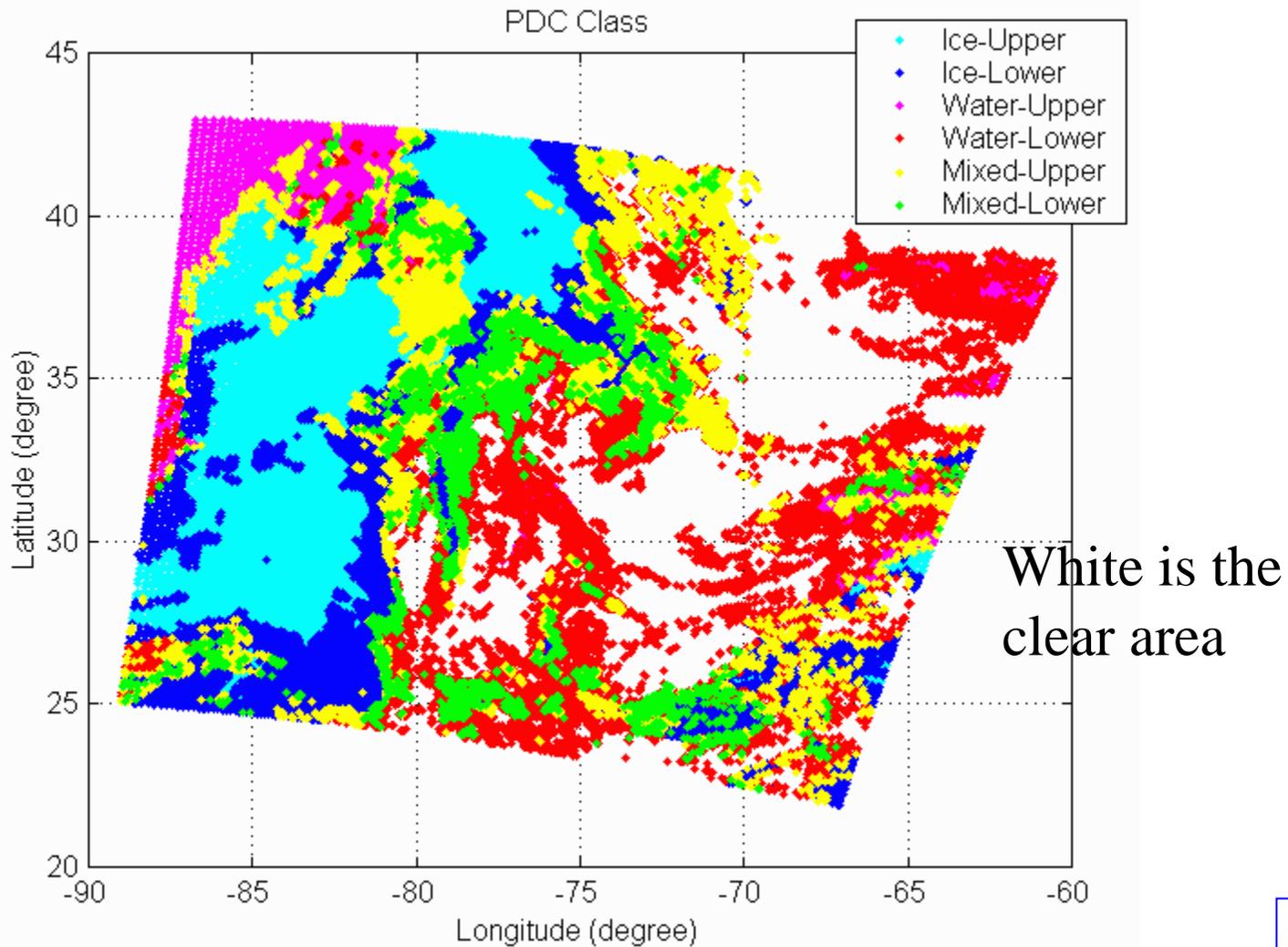


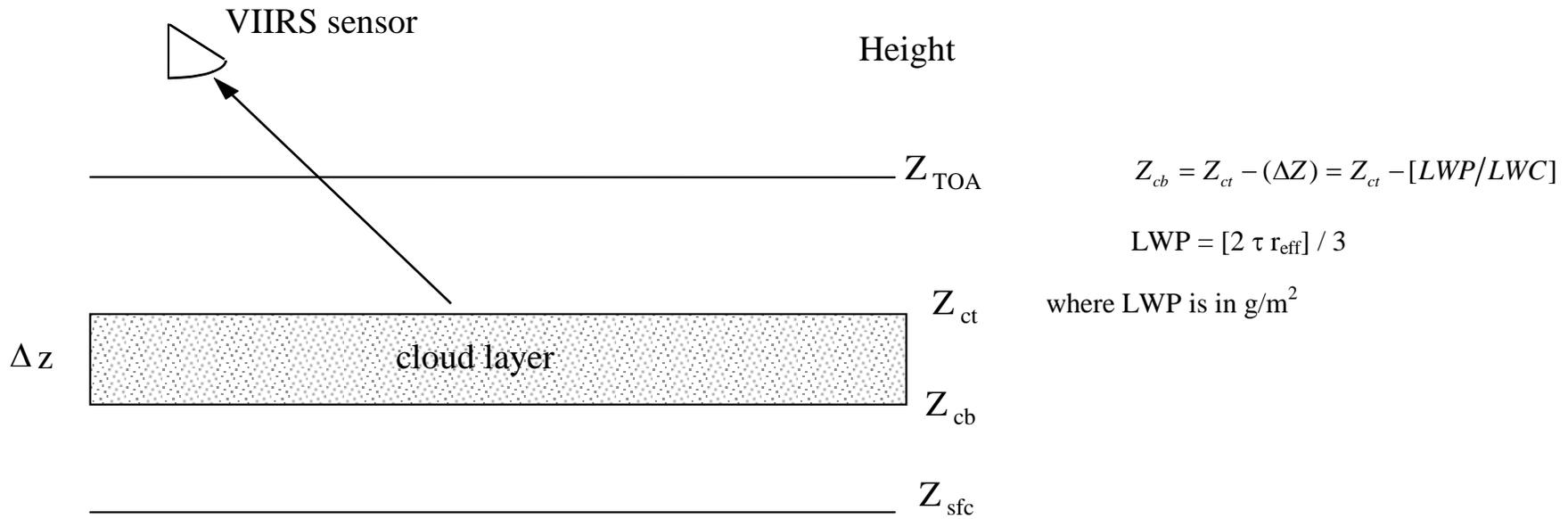
MODIS Cloud Mask/Phase Example

MODIS 2001 152 1600 UTC



VIIRS Cloud Layers Example





$$Z_{cb} = Z_{ct} - (\Delta Z) = Z_{ct} - [LWP/LWC]$$

$$LWP = [2 \tau r_{eff}] / 3$$

where LWP is in g/m^2

$$Z_{cb} = Z_{ct} - (\Delta Z) = Z_{ct} - [IWP/IWC]$$

$$IWP = \tau / [a + b/D_e]$$

with a and b being regression coefficients, defined by Liou (Table 5.4, 1992) with values

$a = -6.656e-3$; $b = 3.686$. Additionally, D_e , IWP, and IWC are functions of cloud temperature. IWC is calculated by:

$$\ln(IWC) = -7.6 + 4 \exp[-0.2443e-3(|T| - 20)^{2.455}] \quad \text{for } |T| > 20 \text{ deg C} \quad (5)$$

The dependence of D_e on cloud top temperature is given in Equations 6 and 7 by Ou *et al.*, (1993). If ice cloud optical depth exceeds 10, enhanced processing could use ice water path taken directly from the CMIS EDR.

$$D_e = c_0 + c_1 T + c_2 T^2 + c_3 T^3$$

(6)

where $c_0 = 326.3$, $c_1 = 12.42$, $c_2 = 0.197$, $c_3 = 0.0012$



Cloud Type	r_e (μm)	LWC (g/m^3)	Δz_{max} (m)
Stratus I (oceans)	3.5	0.24	622
Stratus II (land)	4.5	0.44	436
Stratocumulus	4.0	0.09	1896
Altostratus	4.5	0.41	468
Cirrus	~ 100 ($= D_e$)	~ 0.1 ($= \text{IWC}$)	3333

Thickness of common ice clouds with optical thickness of 10 & water clouds with an optical thickness of 64



Error in τ (%)	Retrieved Cloud Base Height (m)	Error in Base Height (%)	Calculated Cloud Thickness (m)	Error in Cloud Thickness (%)
0	1902.8	0	97.2	0
10	1912.5	0.5	87.5	10
20	1922.2	1.0	77.8	20
50	1951.4	2.5	48.6	50

Impact of errors in optical depth on retrieved Cloud Base Height for stratus (water) clouds with cloud top height of 2 km, optical thickness 10, effective particle size 3.5 microns, and liquid water content of 0.24 g/m^3 .



Error in τ (%)	Retrieved Cloud Base Height (m)	Error in Base Height (%)	Calculated Cloud Thickness (m)	Error in Cloud Thickness (%)
0	6689.2	0	3310.8	0
10	7084.5	5.6	2915.5	11.9
20	7463.2	11.5	2536.8	23.4
50	8508.9	27.2	1491.1	55

Impact of errors in optical depth on retrieved Cloud Base Height for a cirrus (ice) cloud with cloud top height of 10 km, optical thickness 10, effective particle size of 100 microns, and ice water content of 0.1 g/m^3



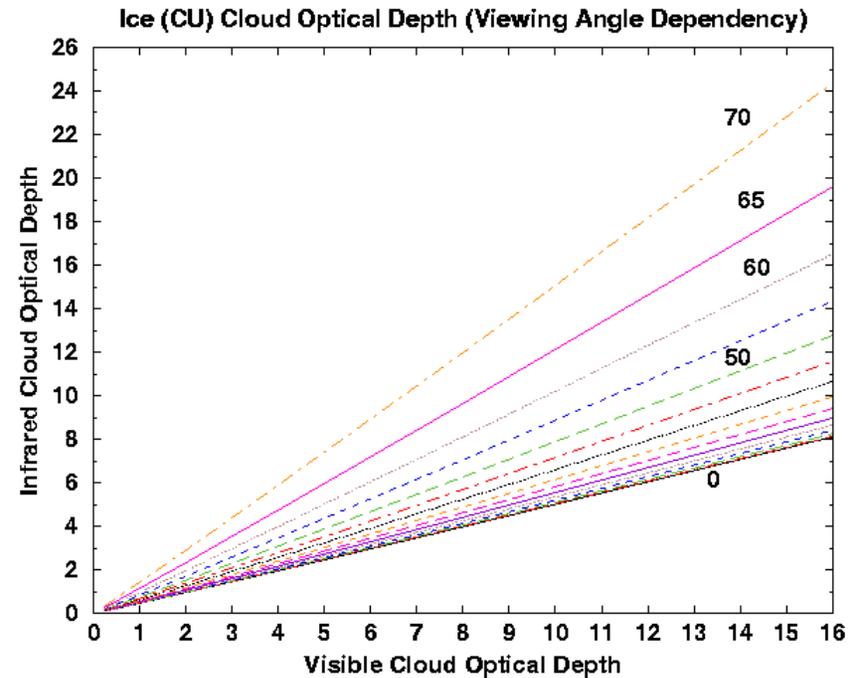
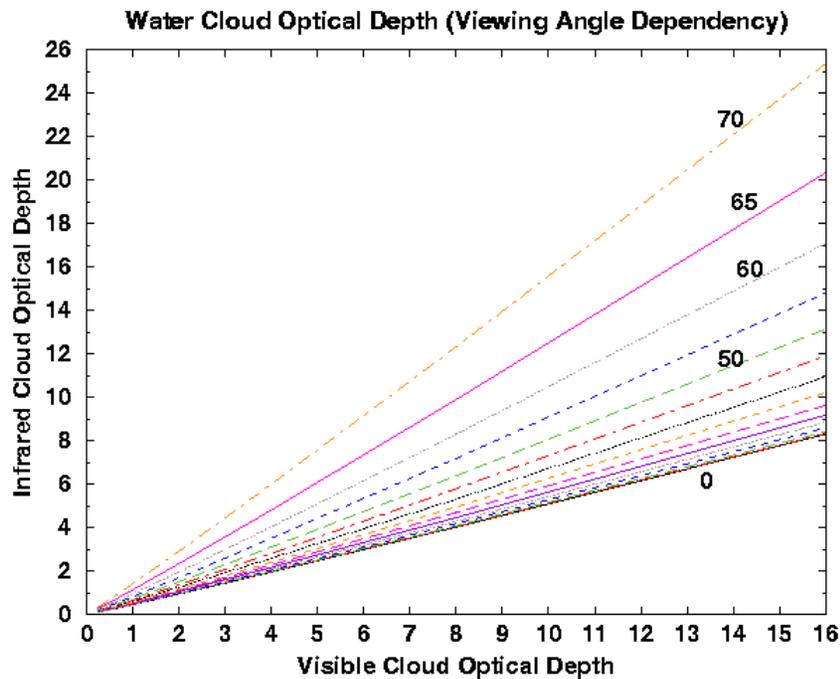
Error in r_e (%)	Retrieved Cloud Base Height (m)	Error in Base Height (%)	Calculated Cloud Thickness (m)	Error in Cloud Thickness (%)
0	1440	4.5	560	10
10	1496	8.6	504	19
20	1552	12.6	448	28
50	1720	24.8	280	55

Impact of errors in effective particle size on retrieved Cloud Base Height. The cloud is identical to that used in Table 4 except that the optical depth of 64 was assumed to have a 10% error. Actual cloud thickness is 622 m



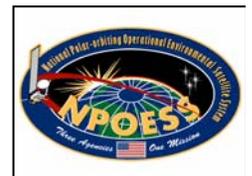
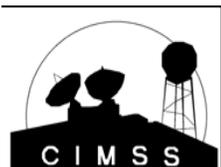
Visible Vs. Infrared Cloud Optical Depth Relationship

Traditional “Old” Thought



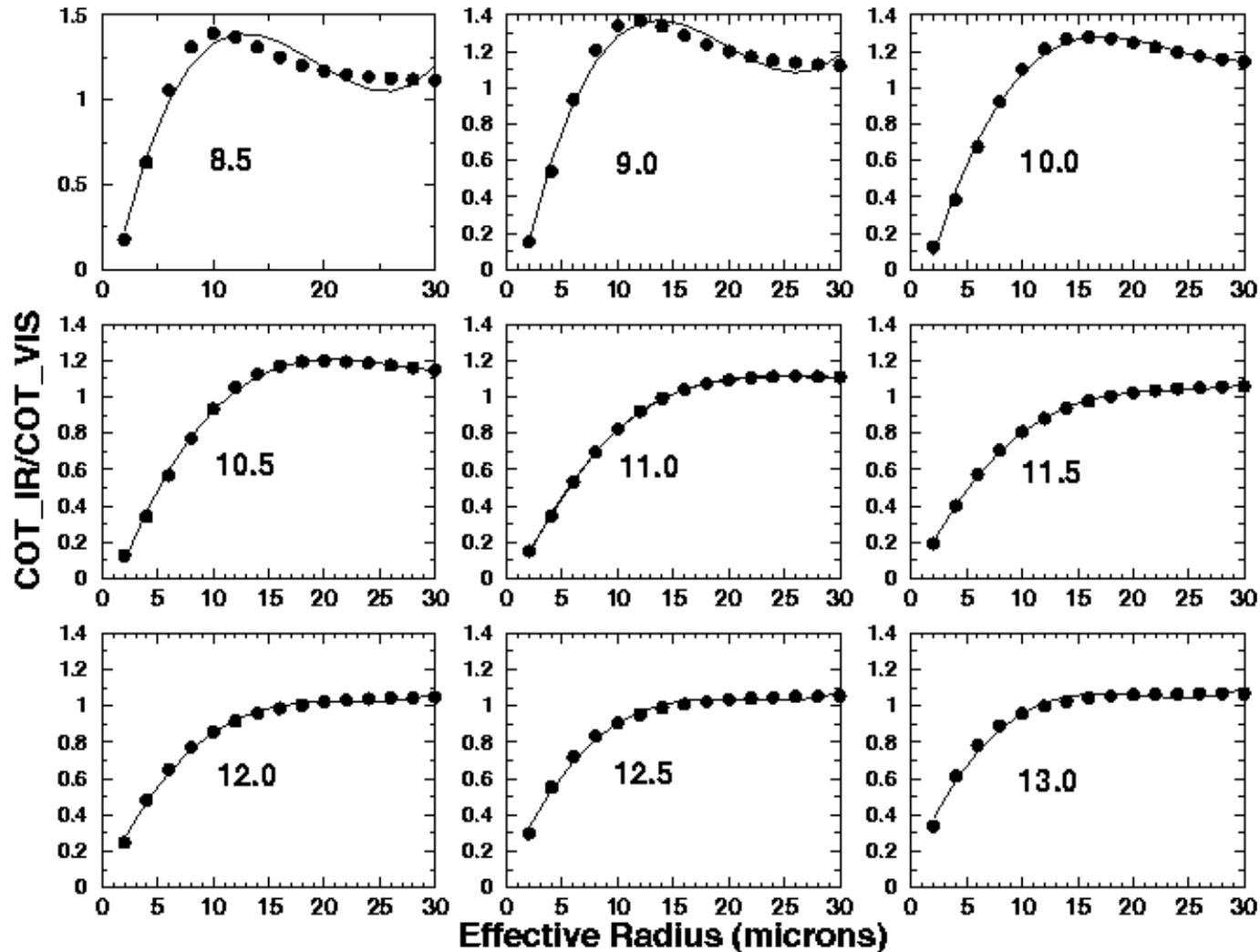
Infrared water (left panel) and ice (right panel) cloud optical depths shown as functions of visible optical depth (0 to 16) and sensor zenith viewing angle (0 to 69 deg)

For 10-11 micron

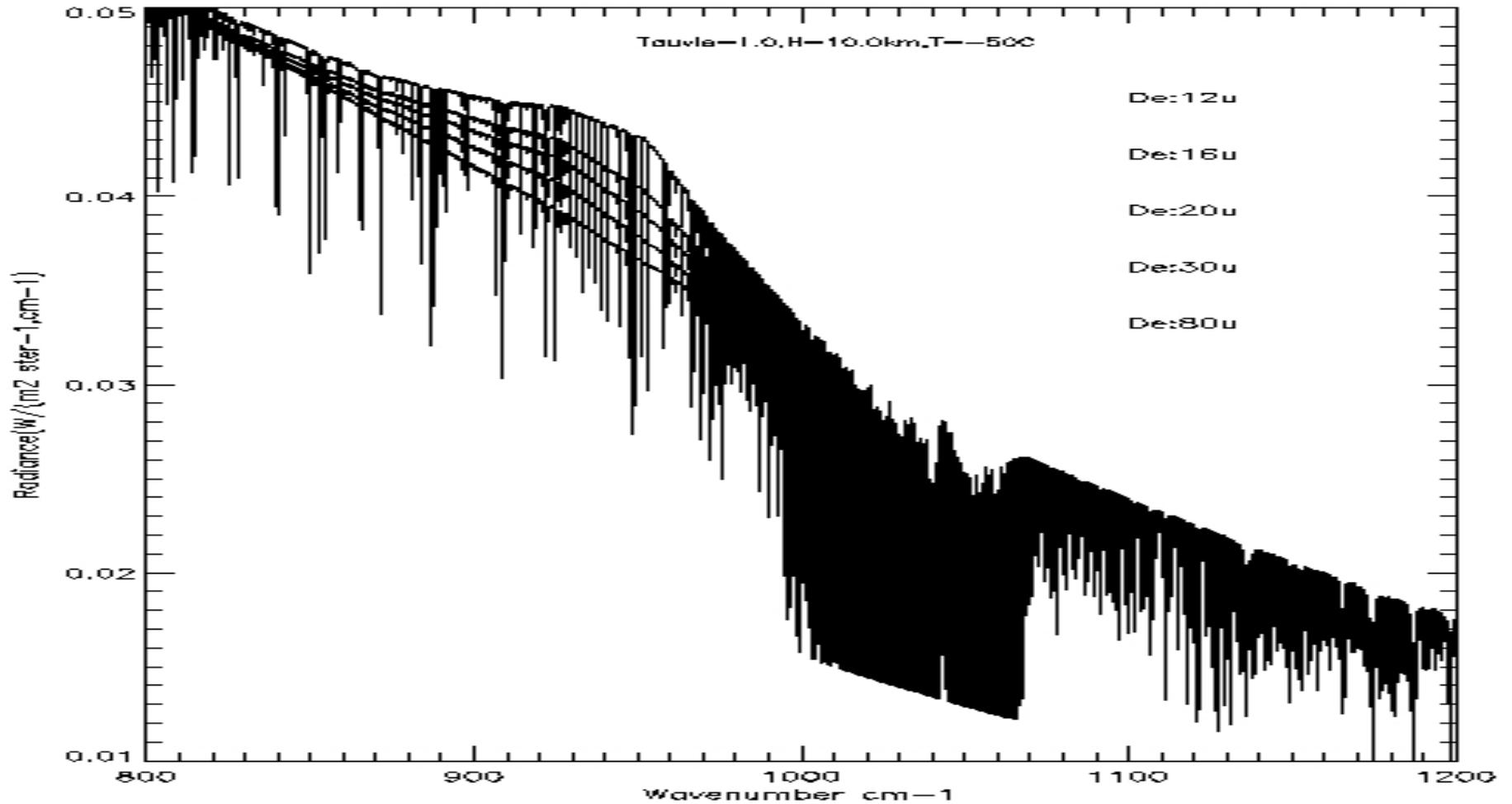


Visible Vs. Infrared Cloud Optical Depth Relationship

Current “New” Thought



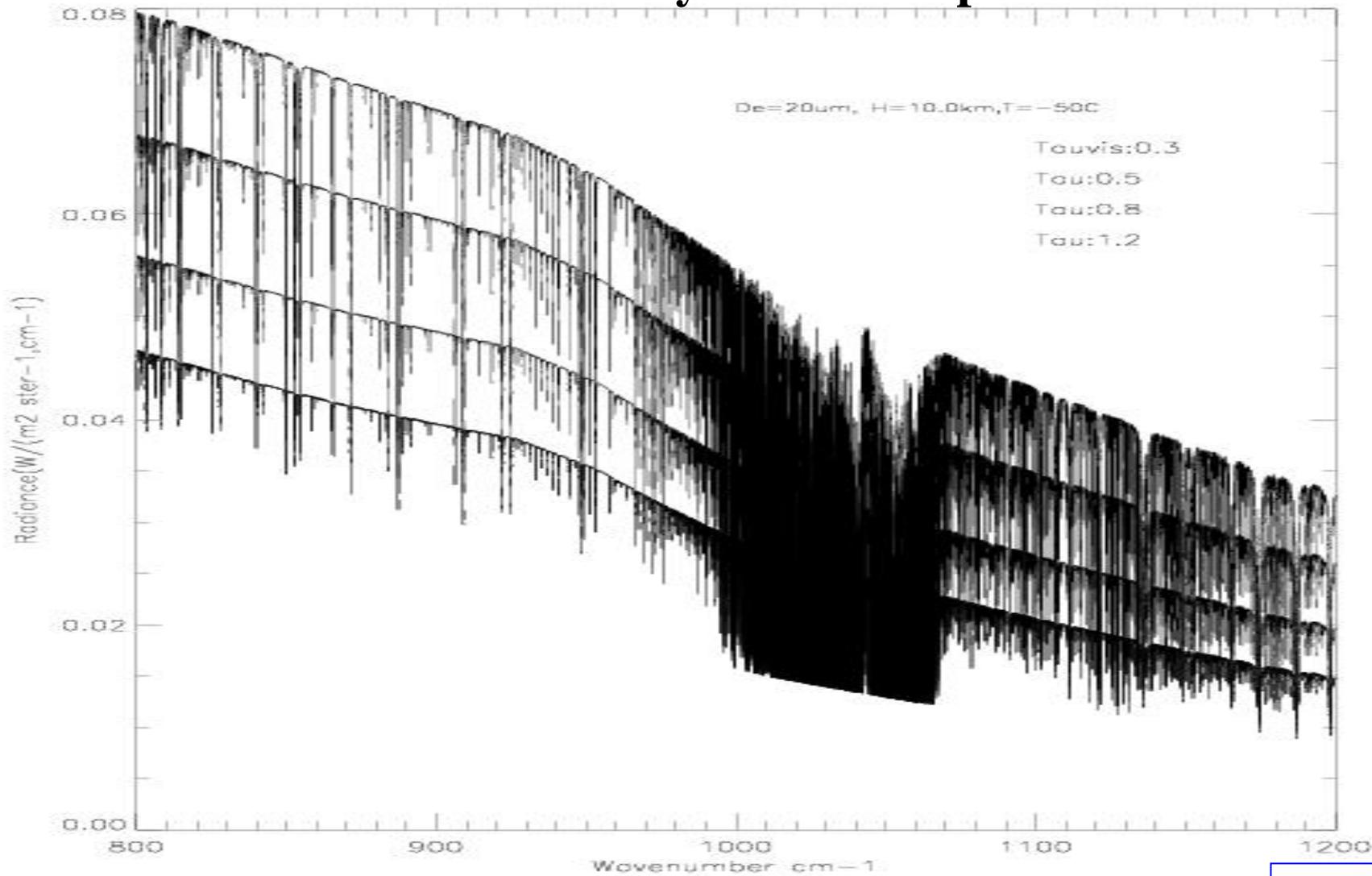
Infrared Radiance sensitivity to Cloud Particle Size



Available by CrIS like measurements



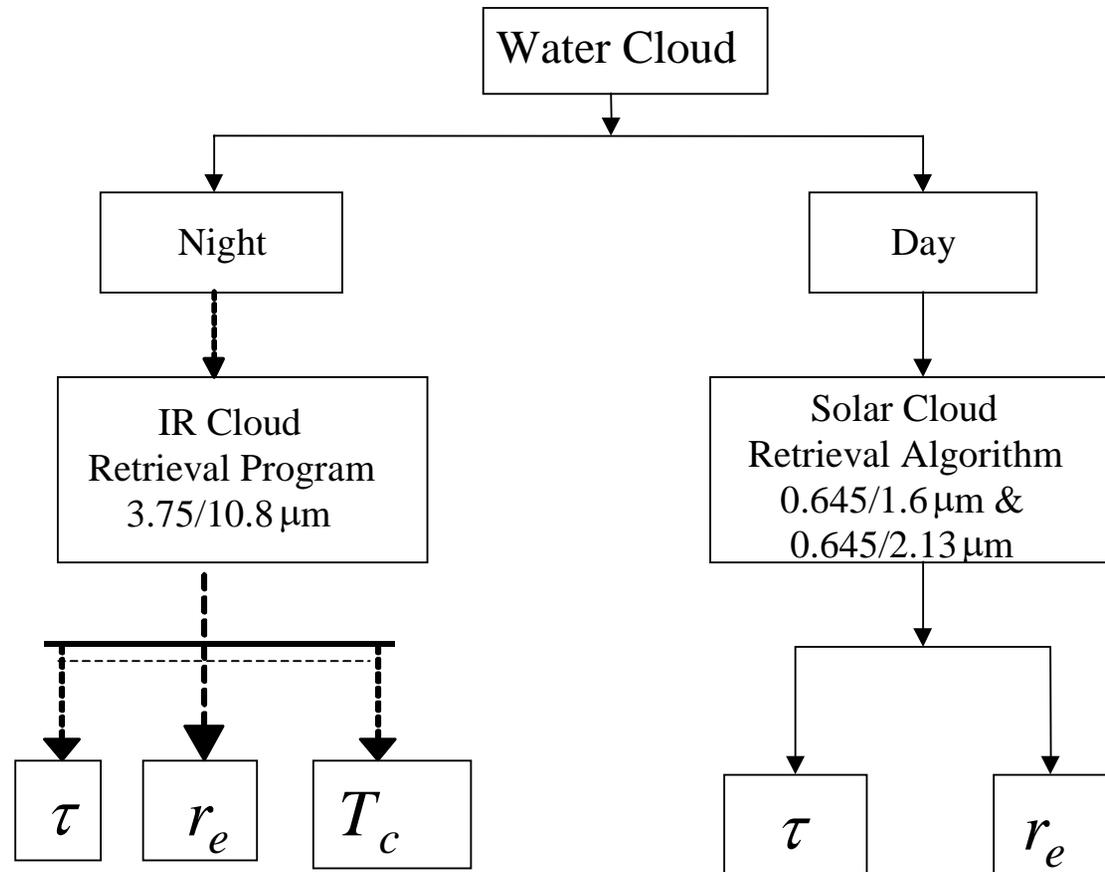
Infrared Radiance sensitivity to Cloud Optical Thickness



Available by CrIS like measurements



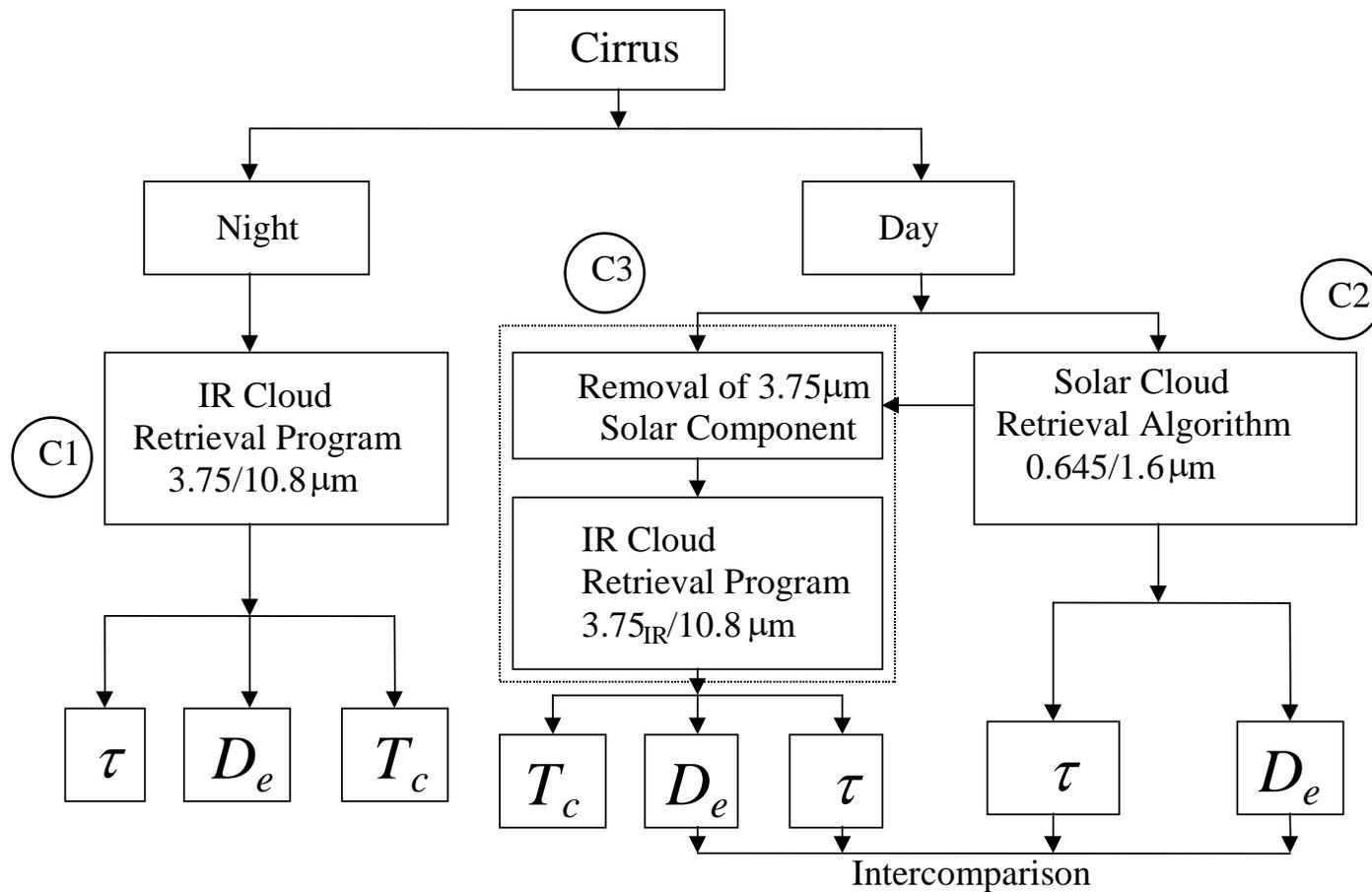
VIIRS Water Cloud Retrieval Program



Two bands approach

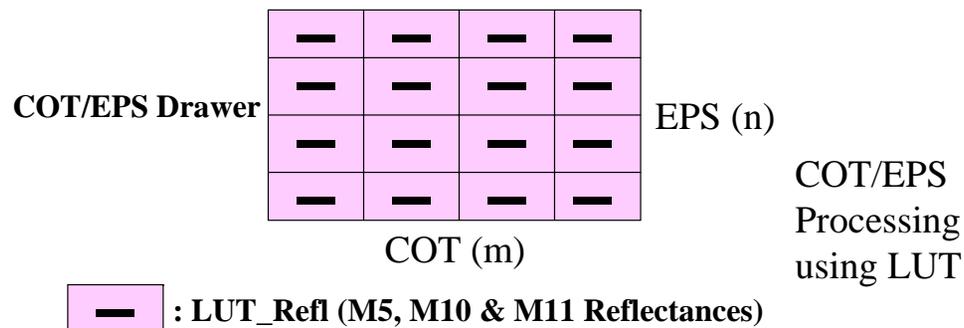
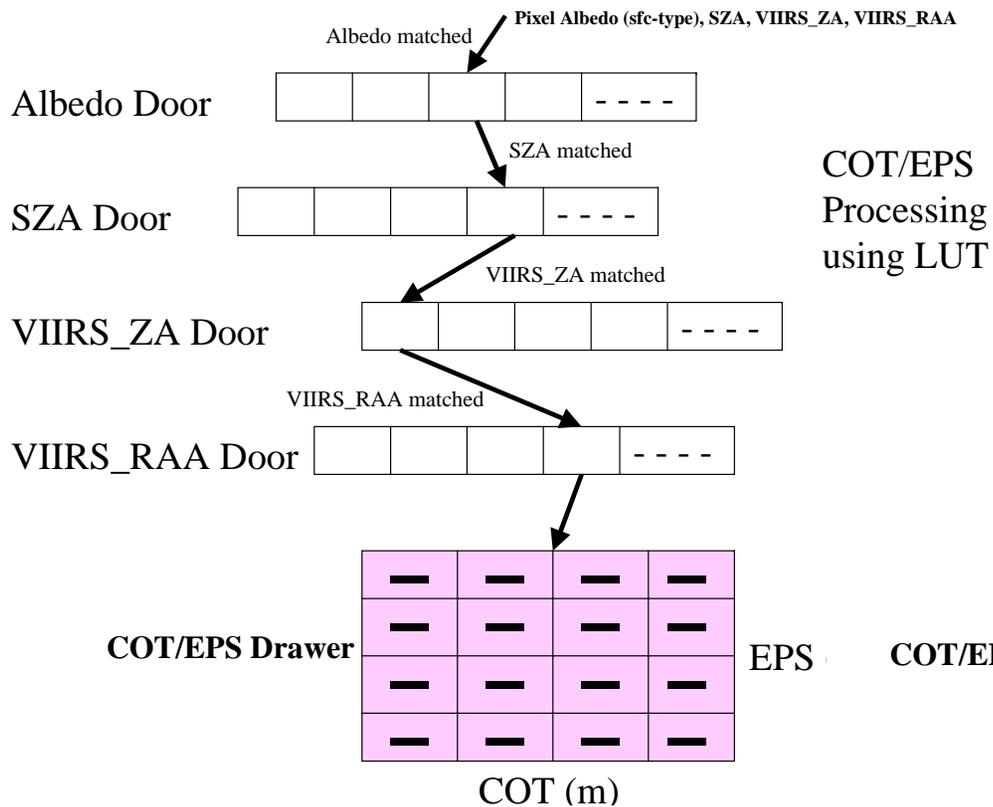


VIIRS Cirrus Cloud Retrieval Program



Two bands approach

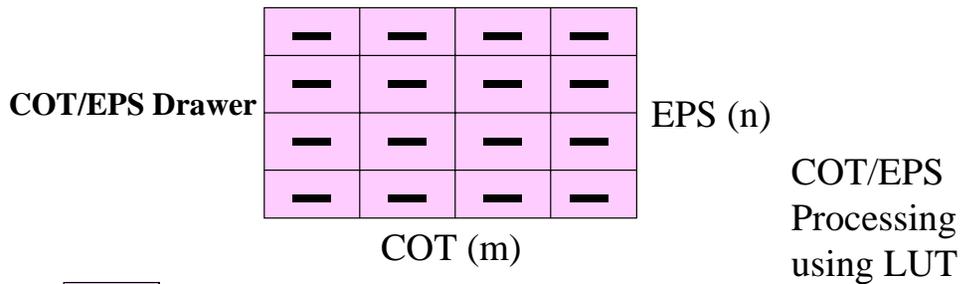




$$\text{Residual}(m,n,i) = \ln(\text{VIIRS_Refl}(\text{pixel},i)) - \ln(\text{LUT_Refl}(m,n,i))$$

$$\text{SSR}(m,n) = \sum [\text{Residual}(m,n,i)]^2 ; i=1,3$$





— : LUT_Refl (M5, M10 & M11 Reflectances)

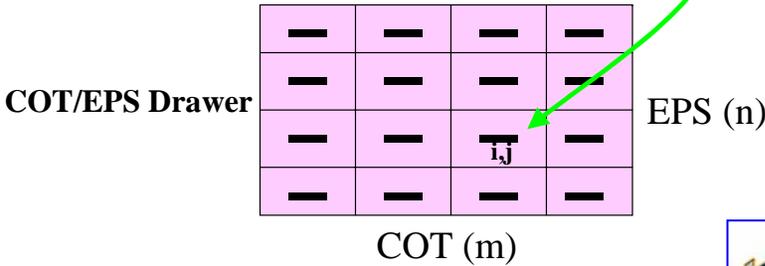
$$\text{Residual}(m,n,i) = \ln(\text{VIIRS_Refl}(\text{pixel},i)) - \ln(\text{LUT_Refl}(m,n,i))$$

$$\text{SSR}(m,n) = \sum [\text{Residual}(m,n,i)]^2; i=1,3$$

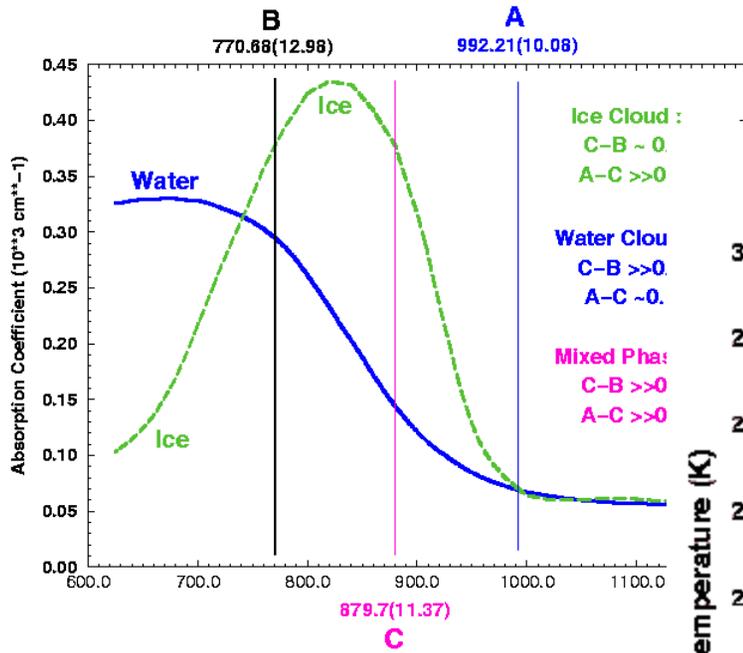
$$\text{SSR}(m,n) = \sum [\text{Residual}(m,n,i)]^2; i=1,3$$

Find Minimum of SSR -> SSR(i,j)
 where $i \subset m$ and $j \subset n$
 COT/EPS in location of i,j
 from the LUT COT/EPS drawer
 is the retrieved EDR

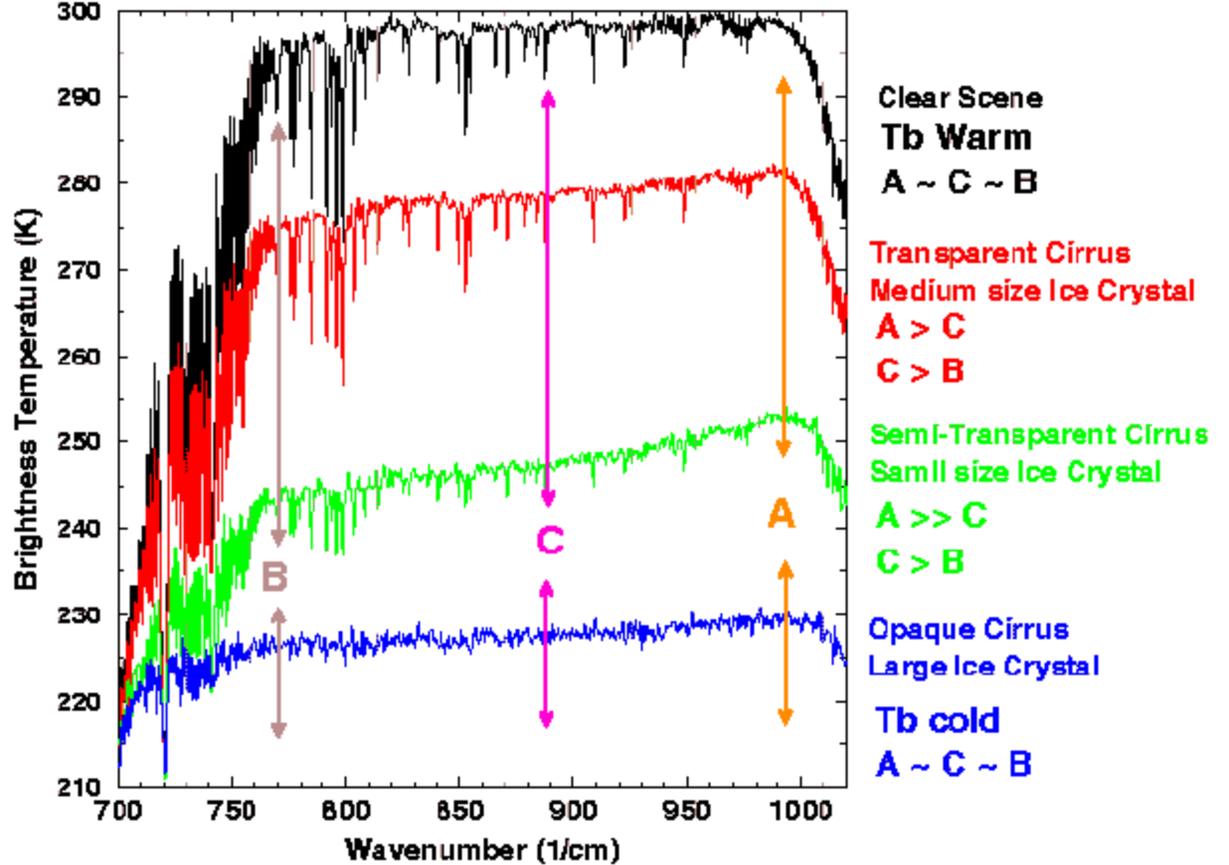
COT/EPS Processing using LUT



CrIS/VIIRS Cloud Phase/Size Sensitivity



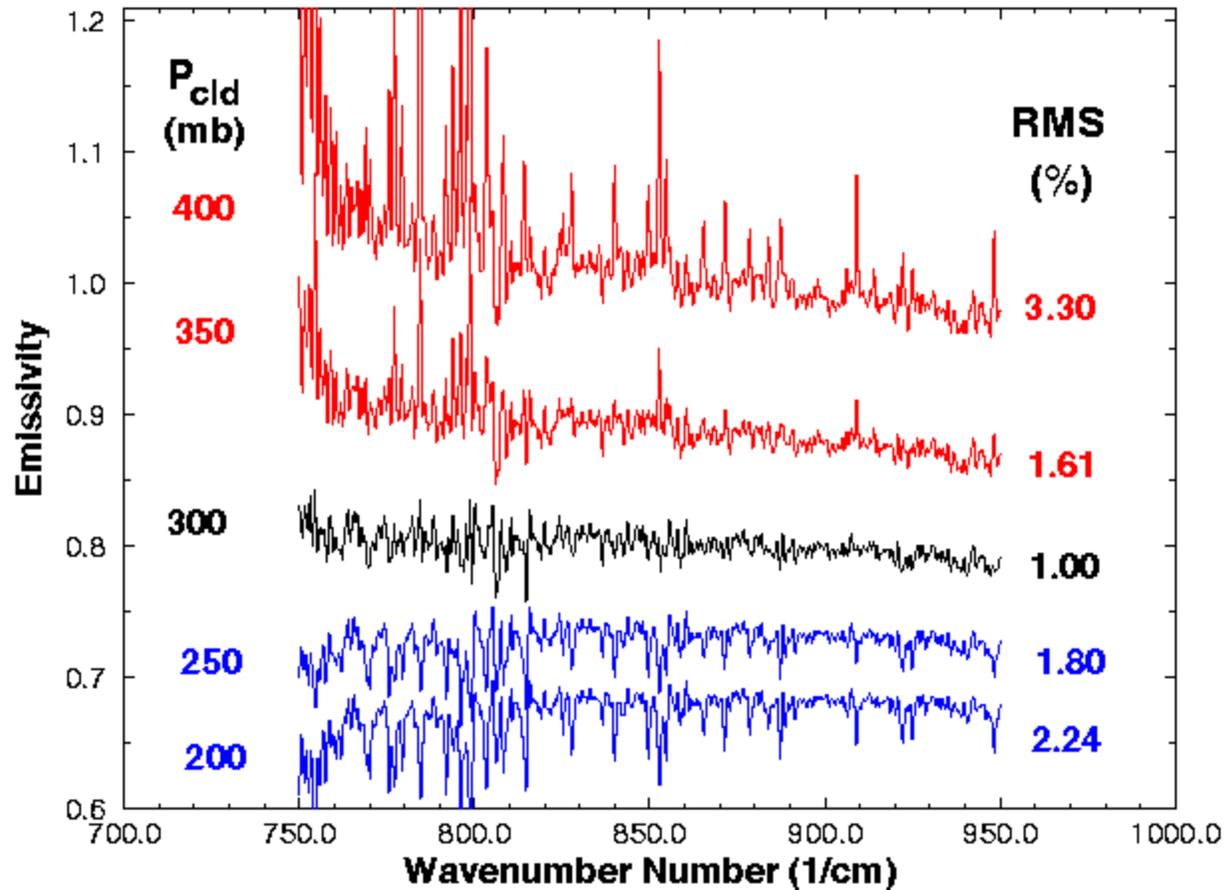
HIS Clear/Cloudy Spectra
 April 16/96, SUCCESS Experiment



Cloud Emissivity Spectrum Retrieval

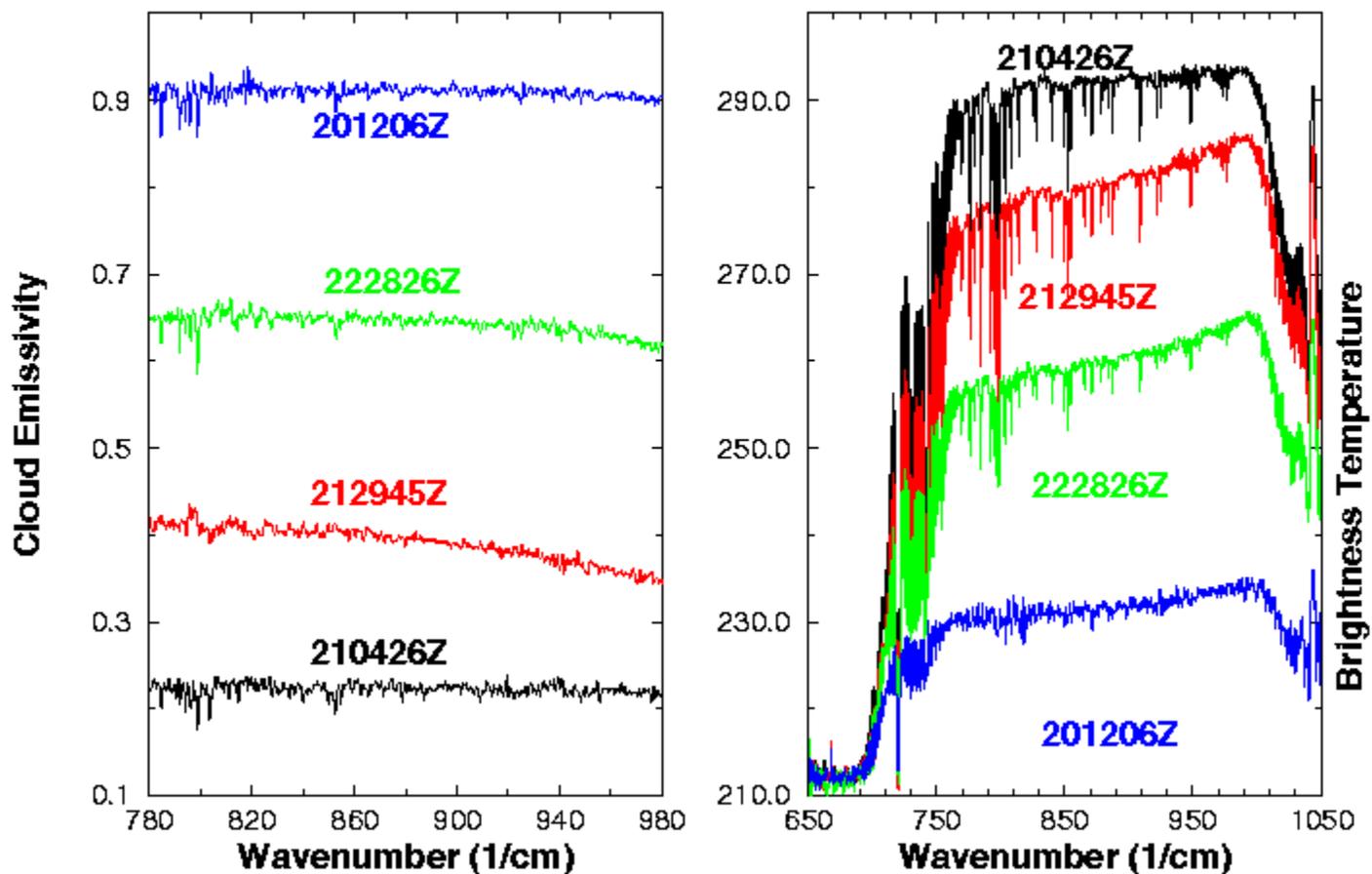
Emissivity Minimum Variance Cloud Height

April 21, 1996 (Lidar Height = 280 mb)

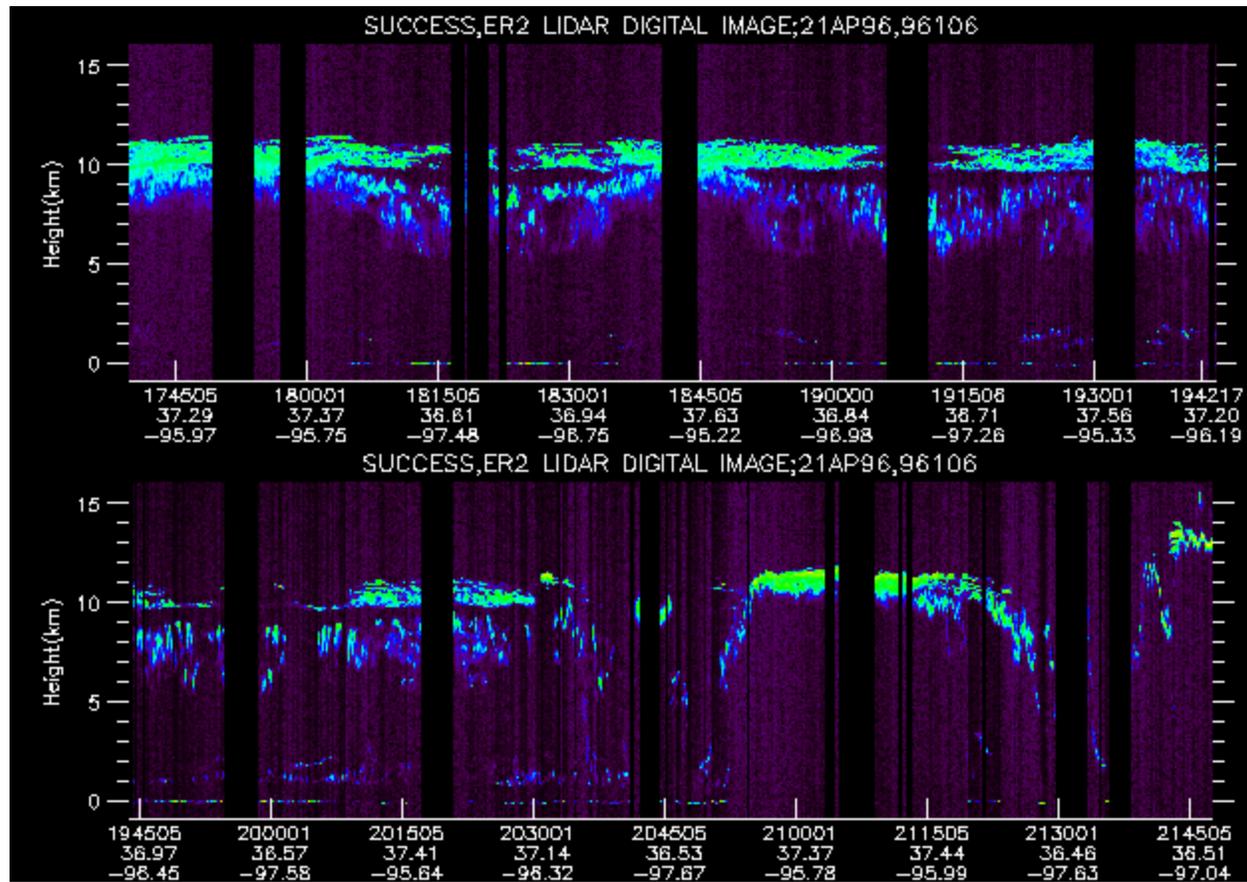


Infrared Cloud Emissivity & Brightness Temp. Spectra

HIS @ SUCCESS - April 16, 1996

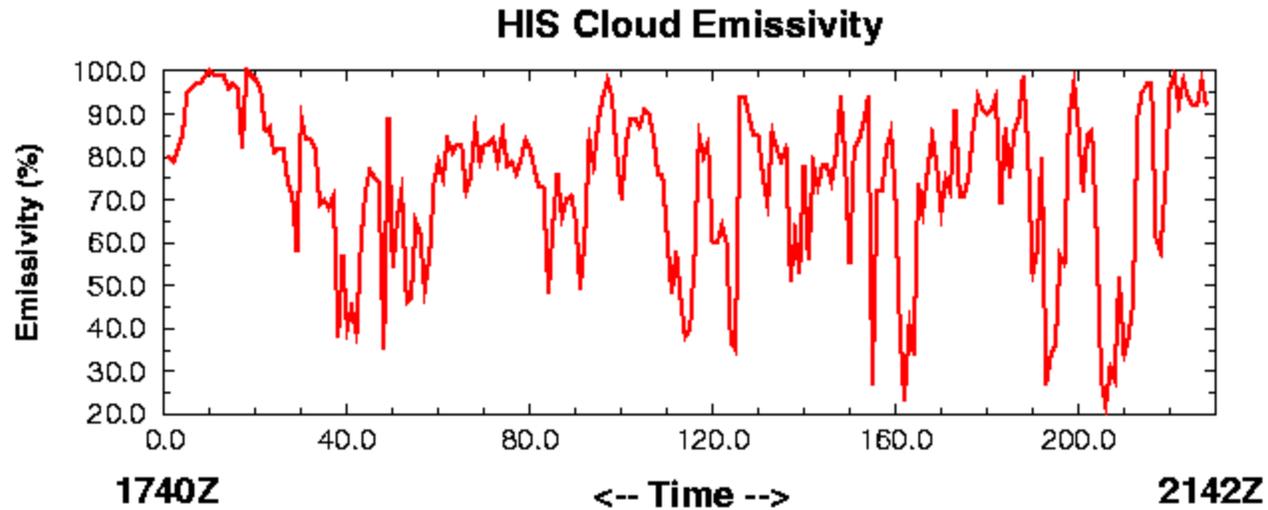
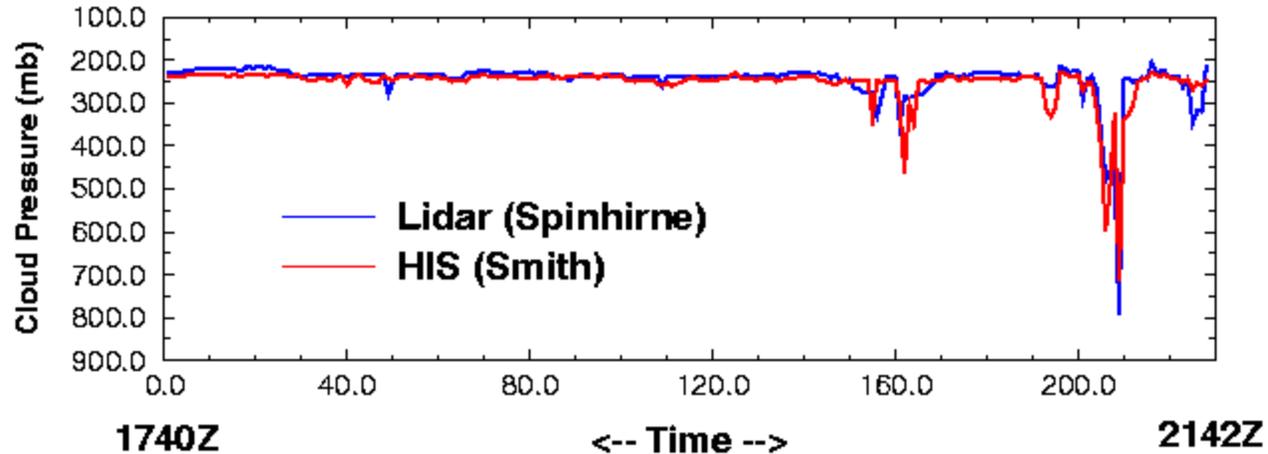


CLS LIDAR Image - Time series (April 21, 1998)

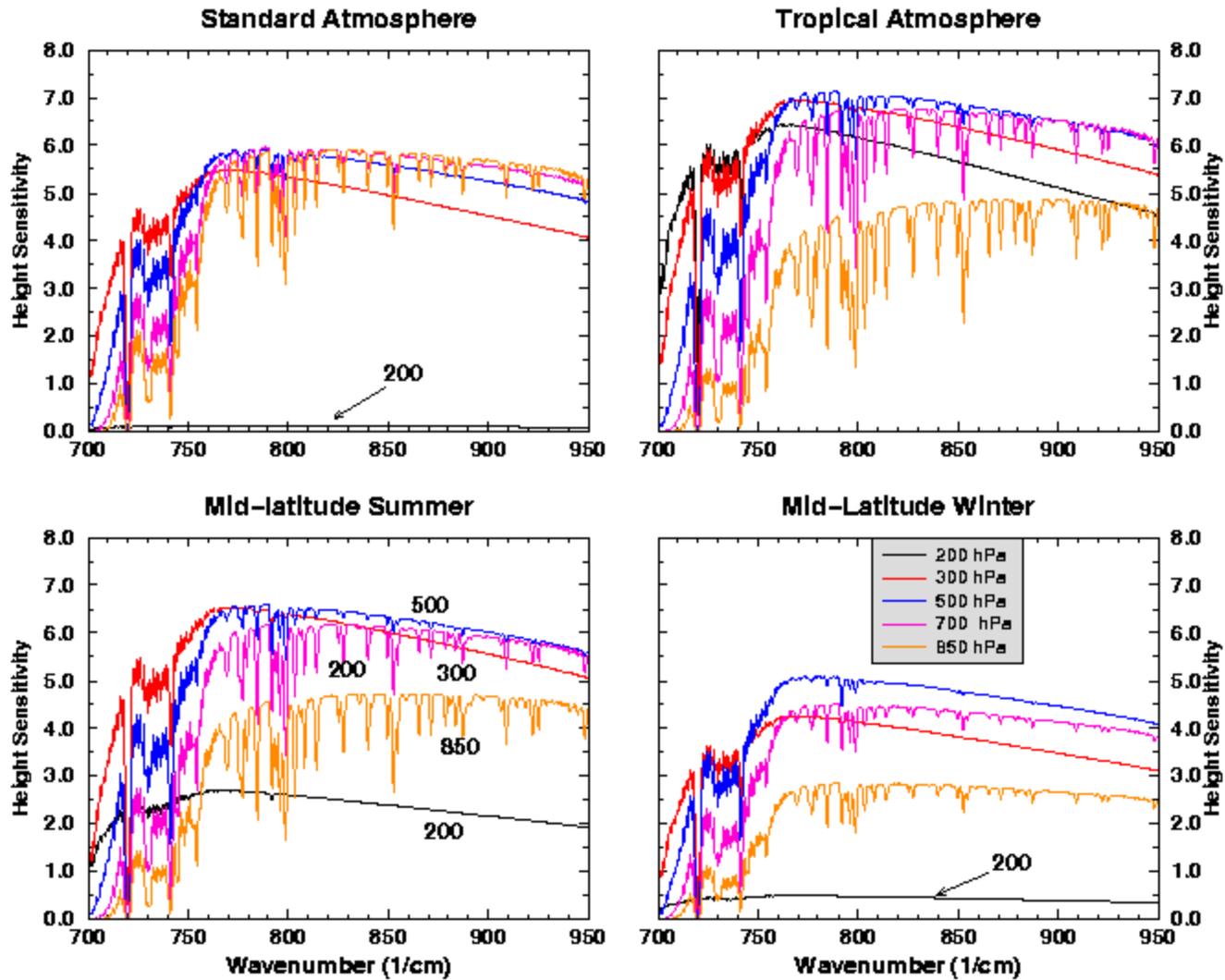


Cloud Height Retrieval & Verification

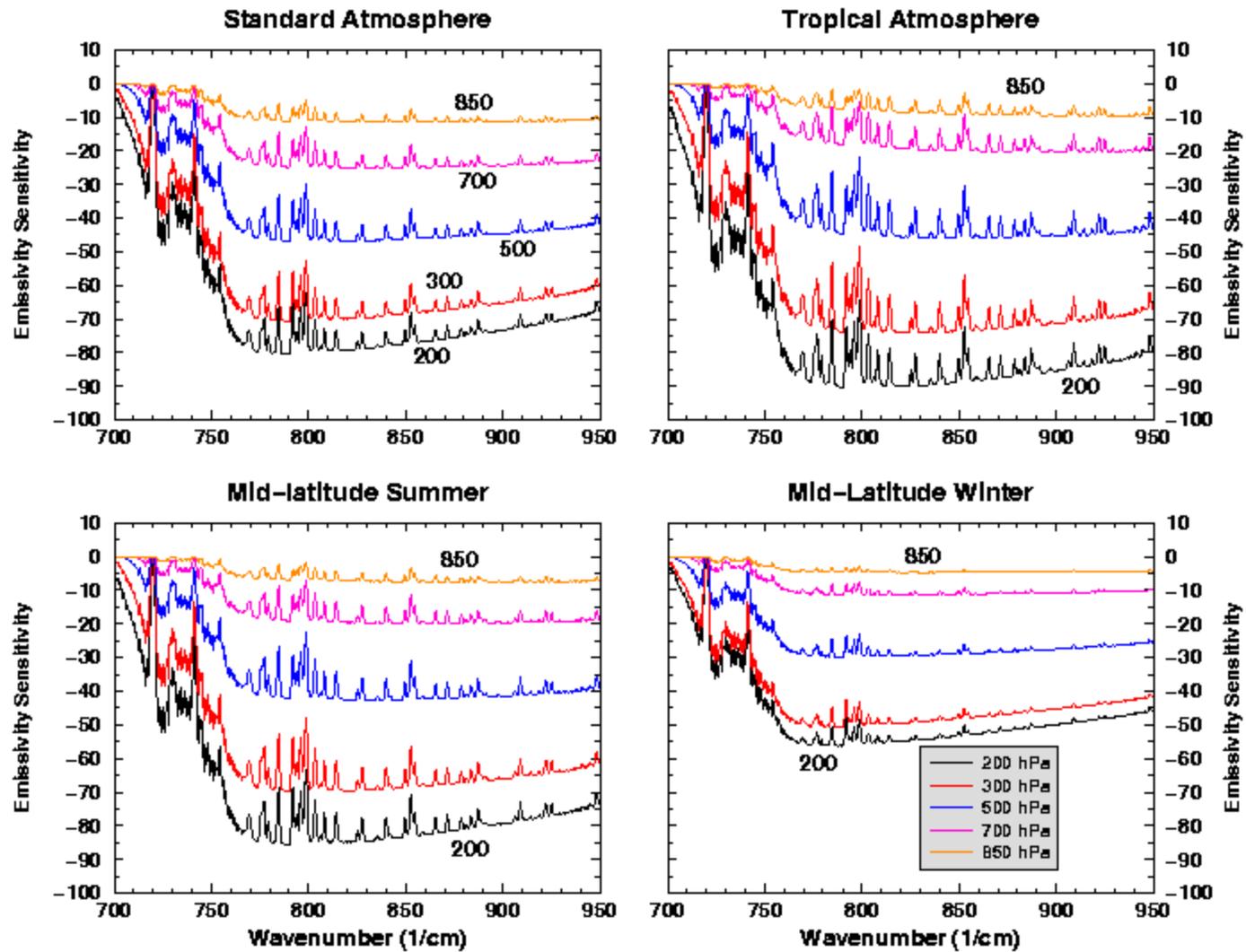
Cloud-Top Pressure (HIS Vs. Lidar)



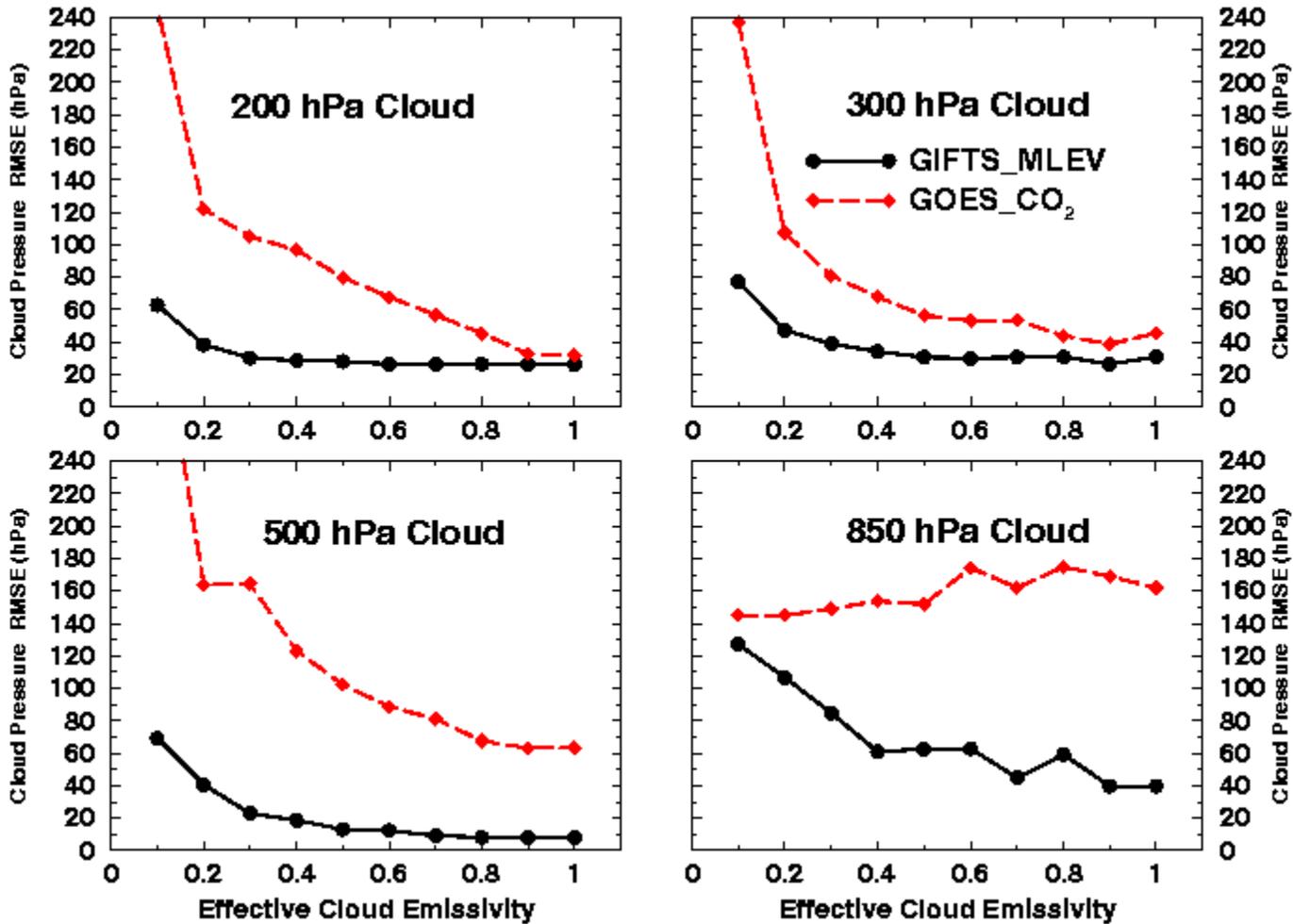
Cloud Height Sensitivity



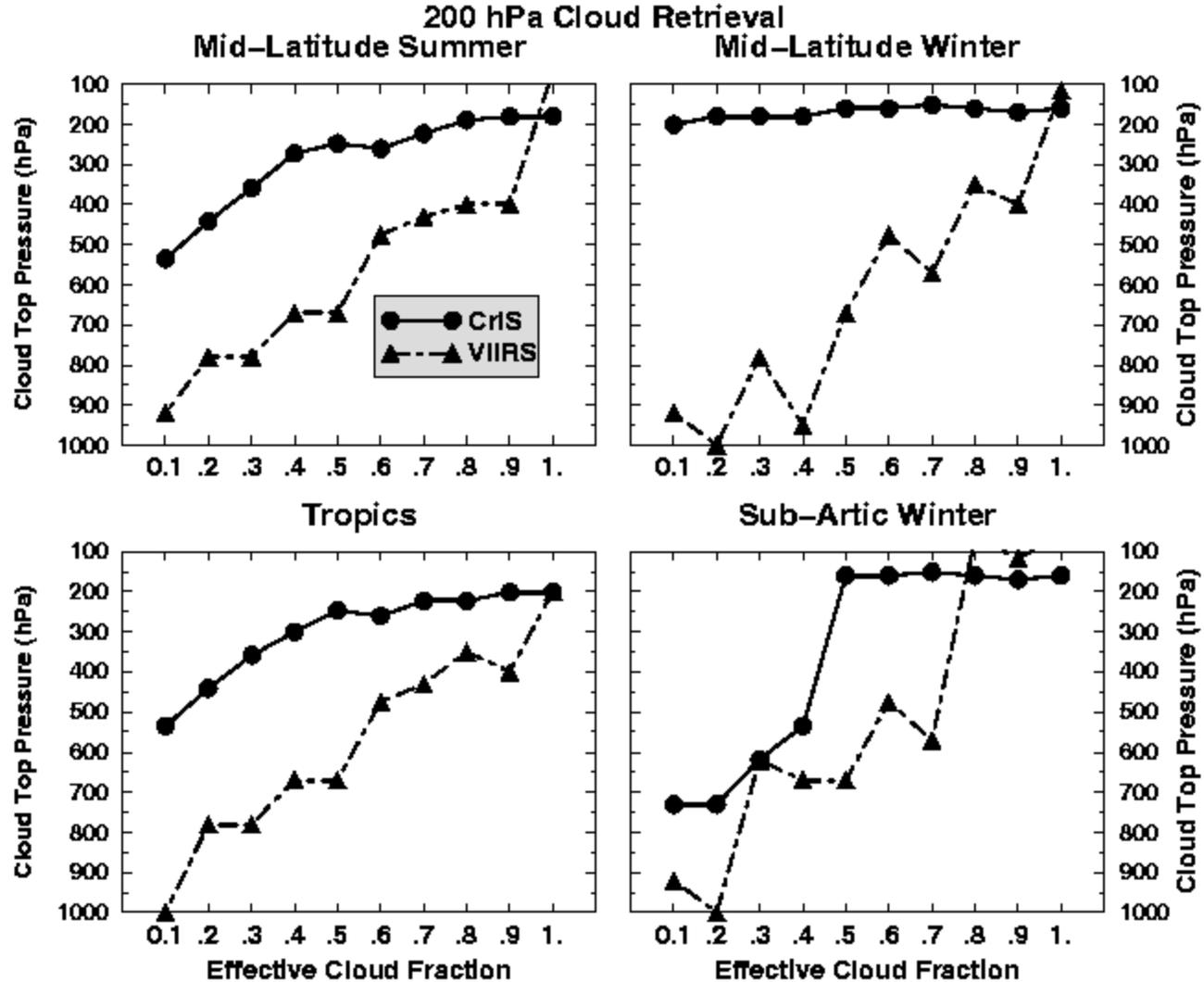
Cloud Emissivity Sensitivity



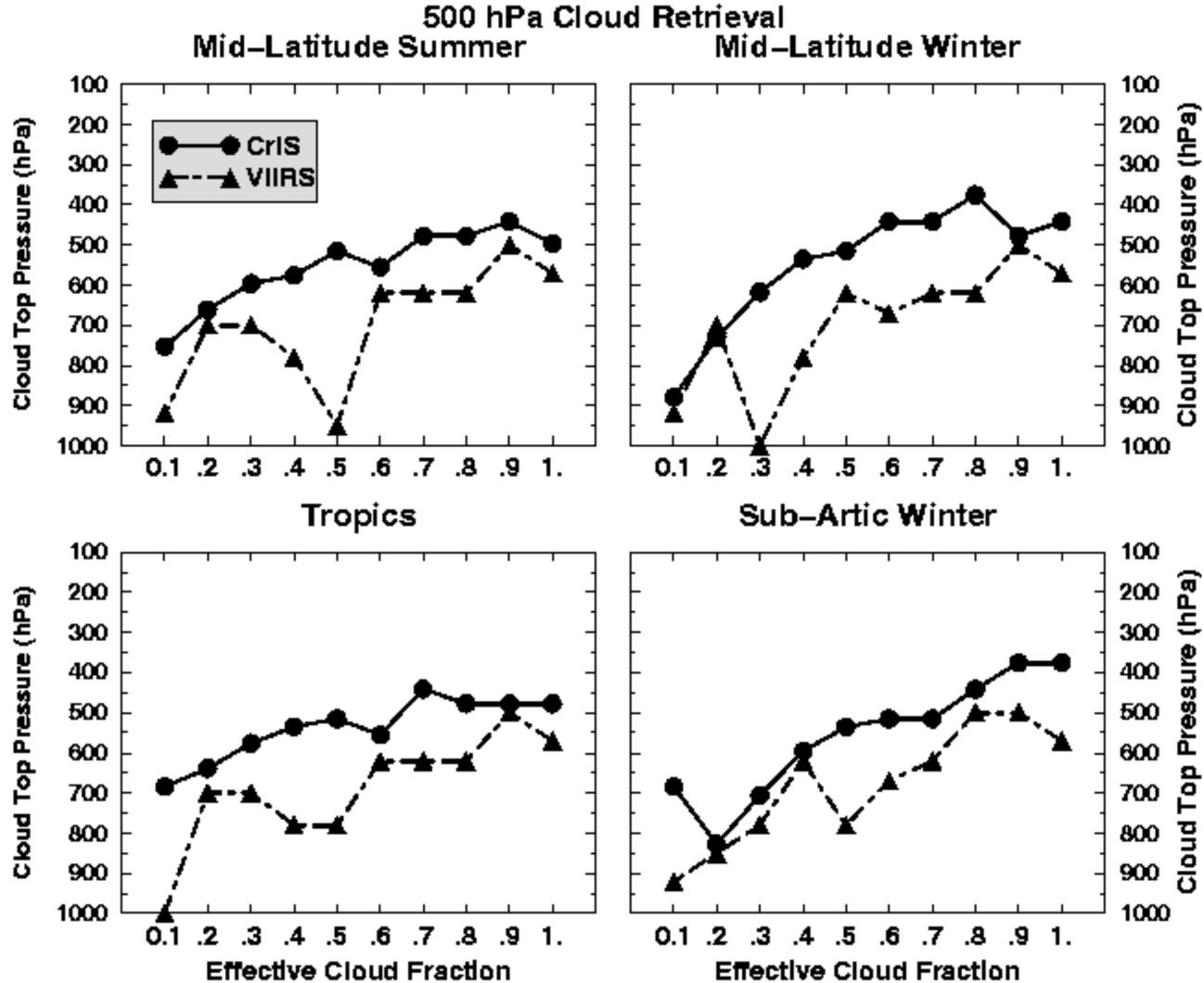
Cloud Height EDR Performance Comparison GIFTS/CrIS Vs. GOES/VIIRS



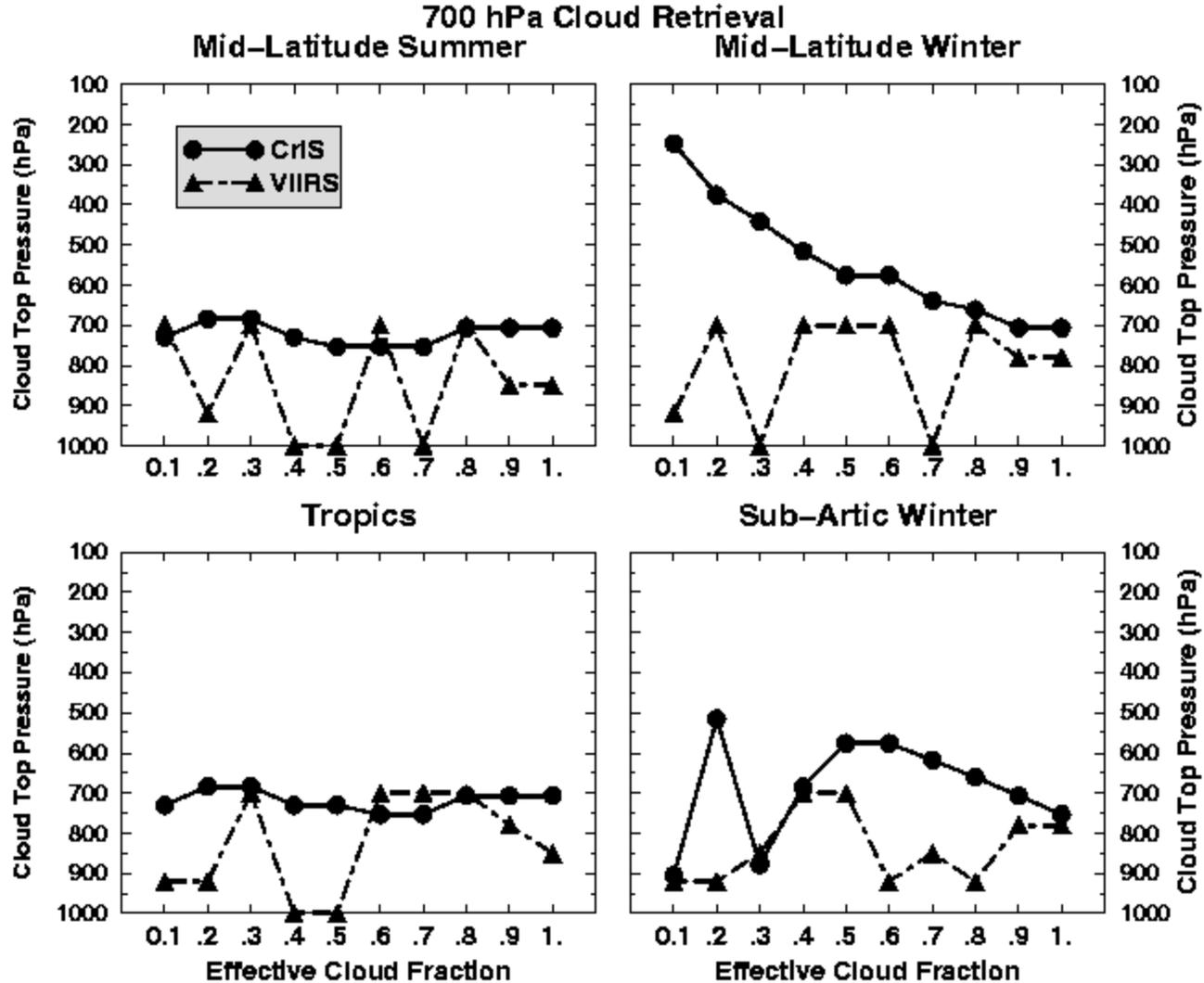
Cloud Height EDR Performance Comparison CrIS Vs. VIIRS



Cloud Height EDR Performance Comparison CrIS Vs. VIIRS



Cloud Height EDR Performance Comparison CrIS Vs. VIIRS

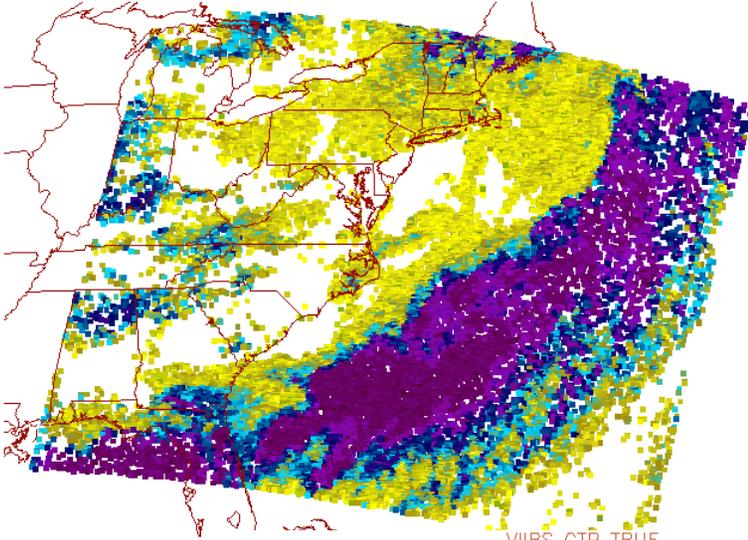


Cloud Height EDR Performance Comparison

CrIS Vs. VIIRS

VIIRS

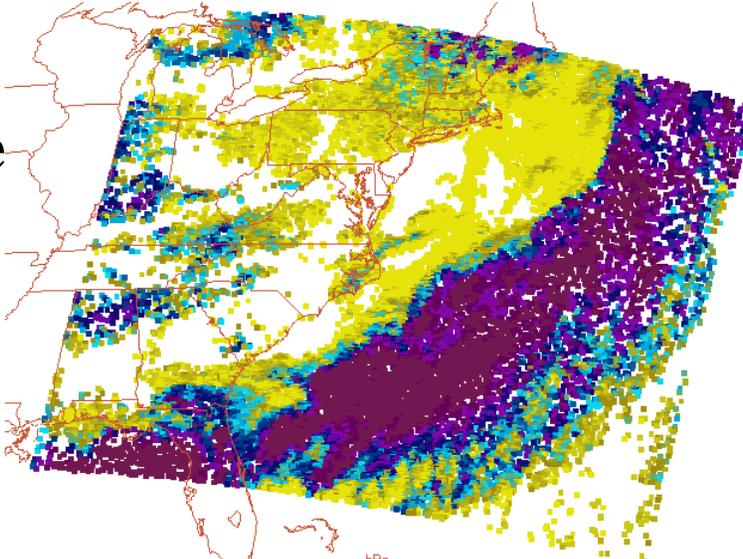
VIIRS CTP RTVL



VIIRS CTP TRUE

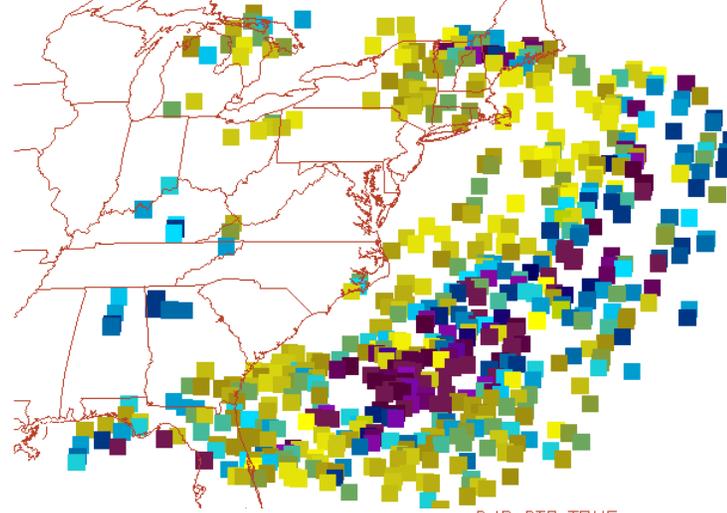


True



CrIS

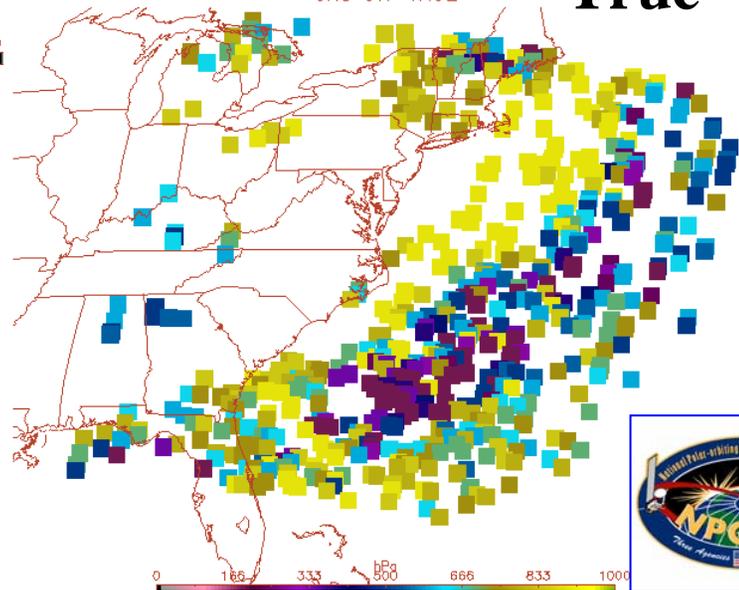
CrIS CTP RTVL



CrIS CTP TRUE



True



Cloud Height EDR Performance Comparison CrIS Vs. VIIRS Vs. Synergy (CrIS+VIIRS)

Cloud Top Pressure Error Histogram

